Title: Streamlined Life Cycle Assessment (LCA) of Alternate Computer Housings

Objective of the Research:

EPA (ORD/NRMRL) is interested in conducting a streamlined Life Cycle Assessment (LCA) of electronic products to begin to answer key questions about the lifecycle impacts of replacing mixed plastics made from virgin sources. The electronic product component that has been selected for study is a computer housing (used in the computer unit and monitor). Alternate housing materials of interest include durable metals, bio-based plastics, and post-consumer recycled plastics.

Background:

The use of electronic products has grown substantially over the past two decades. This has been accompanied by increased use of natural resources, pollutant releases, and waste generation. Although electronics comprise a small percentage of the total municipal solid waste stream, because their use continues to increase, electronic waste generation is steadily increasing. Electronics are the fastest growing component of the solid waste stream in the US. In 2007, discarded TVs, computers, peripherals (including printers, scanners, and faxes), mice, keyboards and cell phones totaled about 2.25 million short tons. Although recycling rates have risen nearly 50% since 2004, and will likely continue to rise, only 18% of these products are currently recycled

EPA's interest in the end of life management of electronic products stems, in particular, from three main concerns:

- 1. Rapid growth and change in this product sector, leading to a constant stream of new product offerings and a wide array of obsolete products needing appropriate management;
- 2. The presence of toxic substances in many products which can cause problematic exposures during recycling or disposal, if these products are not properly managed; and
- 3. The need for widespread, convenient and affordable opportunities to reuse/recycle electronics (with initial emphasis on TVs, PCs and cell phones). Reuse and recovery of electronics is believed to conserve energy and materials embodied in used electronics and reduce the environmental impact of these products.

Plastics have been the building blocks of electronic progress for decades by allowing for miniaturization and light weighting. Although plastics make up a small portion of electronic product waste, the plastic components are the most visible because the "housing," the outer casing that encloses electronics, is often made of plastic. The most popular housing material for laptop computers is a mixture of polycarbonate (PC) and acrylonitrile butadiene styrene (ABS), with the typical blend composed of 60-70% PC and 20-30% ABS. The remaining fraction (typically about 10%) is composed of additives. High impact polystyrene (HIPS), while still used commonly in printers and other electronic equipment, is no longer commonly used in laptop casings.

Resale markets for reuse in the US and abroad, as well as remanufacturing in the US, are relatively small. In the US, most end-of-life (EOL) material is landfilled. Recycling, and the desire to "close the loop," is often promoted as a solution to the end-of-life management of plastics in electronics. However, material is shredded and burned, and metals are recovered, often resulting in unwanted unintended consequences. Furthermore, many people are concerned that recovered mixed plastics have low value (i.e. they are downcycled) and may contain brominated flame retardants (BFRs) and other hazardous compounds. While components vary among different products, computers, monitors, printers and television plastics comprise between 30-60% of the volume (not weight) of electronic products. Most responsible electronics recyclers separate plastic components either through disassembly, or, if the product is shredded, through mechanical separation techniques. Only a small fraction of the plastics recycled are used in new electronics products — most recovered plastics are burned for energy recovery or "downcycled" into products with less value.

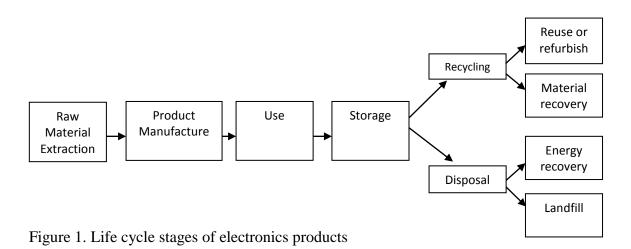
Industry studies and EPA's experience indicate a number of barriers to increasing the volume of recycled content plastic in electronics. Plastic scrap from electronics recyclers are typically a mix of polymers that require separation and classification, which can make them more expensive than virgin materials. In addition, performance needs for new products are difficult to achieve with recycled content, especially for large external components like housings. Another barrier is that older plastic components include substances either considered hazardous or restricted in new products. These include brominated flame retardants such as polybrominated biphenols (PBB) and polybrominated diphenyl ethers (PBDEs). A number of these substances are banned in Europe under the Restriction on Hazardous Substances (RoHS).

Even with these concerns, there is growing interest in using post-consumer recycled plastic in the manufacturing of new electronic equipment. A number of national and international standards and ecolabels for electronics provide requirements or incentives for including post-consumer recycled content in products. This is driven by the assumption that recycled content plastic has significant environmental benefits over the use of virgin materials, especially due to reductions in resource extraction, refining, and to provide a beneficial use of what is largely a "waste" material.

Given the performance and supply limitations of recycled plastics, manufacturers also are consideringe the use of alternate materials to make computer and monitor casings. The most promising bio-based material appears to be polylactic acid (PLA), as either the principal constituent or as a supplement to the housing plastic. Although the material has not been adopted widely, it shows potential in this application. PLA has been used by Fujitsu in their BIBLIO notebook model and as a blend with other plastics. The use of plastic composites made from rapidly-renewable material, such as bamboo, is also being investigated. Another option is to use durable metals, such as magnesium alloy and aluminum. Metals are used currently to make laptops that can withstand rugged use. The feasibility of these options will be further explored in this effort.

The life cycle impacts of all these options are not fully understood. LCA (ISO 14040; ISO 14044) is an effective tool to quantitatively compare the environmental risks associated with

competing products, or product redesign. LCA helps decision makers realize the potential benefits of their product choices in a manner that is safe for both consumers and the environment. There are three primary areas that must be considered in order to recognize the life cycle points of impact for a given electronic product: (1) material manufacture, (2) the electronic product manufacture, (3) use and maintenance, and (4) final disposal. Distribution and transportation activities are also captured across the supply chain (see Figure 1).



The life cycle impact assessment (LCIA) phase of an LCA translates the input/output life cycle inventory (LCI) data into potential human health and environmental impacts. Impact assessment should address ecological and human health effects; as well as resource use and depletion. A life cycle impact assessment attempts to establish a linkage between the product or process and its potential environmental impacts. The following is a list of impact categories and endpoints that identify the impacts.

- Global Warming polar melt, soil moisture loss, longer seasons, forest loss/change, and change in wind and ocean patterns.
- Ozone Depletion increased ultraviolet radiation.
- Resource Depletion -decreased resources for future generations.
- Photochemical Smog "smog," decreased visibility, eye irritation, respiratory tract and lung irritation, and vegetation damage.
- Acidification building corrosion, water body acidification, vegetation effects, and soil effects.
- Human Health increased morbidity and mortality.
- Terrestrial Toxicity decreased production and biodiversity and decreased wildlife for hunting or viewing.
- Aquatic Toxicity decreased aquatic plant and insect production and biodiversity and decreased commercial or recreational fishing.

- Eutrophication nutrients (phosphorous and nitrogen) enter water bodies, such as lakes, estuaries and slow-moving streams, causing excessive plant growth and oxygen depletion.
- Land Use loss of terrestrial habitat for wildlife and decreased landfill space.
- Water Use loss of available water from groundwater and surface water sources.

Key Questions -

- What are the potential replacements for virgin plastics in electronic products, such as post consumer recycled plastics, metals, or bio-based materials made from rapidly-renewable materials like bamboo?
- What are the environmental consequences on a life cycle basis of casings made from alternate materials?
- How might switching from current plastics to alternate materials impact recyclability or transportation (by increasing/decreasing product weight, for example)?
- What are the current impacts of brominated flame retardants (BFRs) and other additives in plastics used in computer casings on recyclability?

Purpose of the Work Assignment:

The purpose of this effort is to obtain support in the collection of LCI data and impact data which will be applied by EPA using the OpenLCA open source software (www.openlca.org) followed by using EPA's TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) software to complete the LCA. The assumption is that the electronic components of the computer are unchanged so that only the computer housing is considered. The assessment will take into account the complete life cycle ranging from manufacturing (including all steps from material extraction up to the final assembly), distribution (from production site to the use site), functional life span, up to the EOL treatment (including recycling and disposal operations). The results are intended to support EPA decision makers in their analysis of alternatives to plastics in electronic products.

Specific Tasks:

The Contractor shall possess in-depth knowledge of LCA methodologies and approaches (including OpenLCA and EcoSPOLD) and have expertise in identifying and gathering relevant LCI data and information for LCAs. In addition, the Contractor shall possess in-depth knowledge of the electronic product industry. The work to be completed and the schedule of deliverables are included in the 6 tasks detailed below.

Task 1 - Quality Assurance Project Plan (QAPP)

The Contractor shall submit a written quality assurance project plan (QAPP) describing the methods that will be used to verify and validate all LCI data and impact data gathered from secondary data sources (no primary data will be collected in this streamlined LCA). The contractor shall refer to the guidelines in the Standard Operating Procedure for Life Cycle

Assessment Projects Involving Data Collection (to be provided at time of contract award) when writing their QAPP. The contractor shall submit the QAPP to EPA within 20 days of award of the contract. The EPA task manager will submit the draft QAPP for internal review and approval. The Contractor shall revise the QAPP in order to fully address the EPA review comments. EPA approval of the QAPP must be obtained before the Contractor may begin Task 3 (data collection).

Task 2 -Preparation of Background Report

The Contractor shall conduct a search of the open literature to collect and report relevant information on the manufacture of computer monitors using plastics, resins, and blends, as well as alternate materials that are currently used are maybe used in the near future. The Contractor shall also report on current end-of-life management of computers, focusing on the plastic components. The outcome of this background information will help EPA form the basis of the LCAs to be conducted, specifically in the definition of the goal and scope of the LCA. At a minimum, the report shall address the following topics:

- How computer housings are currently made and from what materials;
- Types of plastic resins (including blends) predominantly used in the manufacturing of consumer electronics;
- The current state of plastic recycling and the relevance to computers in the US;
- Materials that are being used or can be used instead of virgin plastic and how these alternative perform (i.e. useful life) in comparison to current plastic housings;
- Published LCAs evaluating computer housing alternatives (or studies on computers that include the housing component).

The contractor shall prepare a brief report (approximately 10 pages) of the findings including full citations and annotated bibliography. This task can occur concurrently with Task 1 but must be completed before beginning Task 3 (data collection).

Task 3 - Collection of Inventory Data

The Contractor shall collect relevant LCI data according to the goal and scope definition established by the EPA for the effort. The exact product systems will be specified by the EPA after considering the outcome of Task 2 but the product systems will include monitors made from (1) a typical plastic or plastic mixture; (2) metal, (3) a bio-based material, and (4) recycled plastic. Following the LCI data collection approach described by the ISO standards and the EPA guidance manual for LCA (EPA 2006), the Contractor shall access secondary sources such as academic journals, patent literature, LCI databases (such as ecoinvent and GaBi), government reports, trade groups, investment reports, manufacturer's data and any other data sources available in the public domain.

The contractor shall follow the procedure for entering and documenting data established in the EPA's Standard Operating Procedure for Life Cycle Assessment Projects Involving Data Collection. Following this SOP, the Contractor shall collect LCI data from secondary data

sources available in the public domain to describe the material acquisition, manufacture, use, disposal, and recycling of computer monitors. The contractor shall follow the QAPP established for the effort (Task 1). All material and resource input flows, material output flows, environmental releases (to air, water, and land), and electrical usage will be as complete as possible to fully characterize all impacts being reported. LCI data needs for this effort include a general description (with flow diagram) of all relevant manufacturing processes for a computer monitor. The Contractor shall retain information on modeling assumptions along with a references and data sources, indicating data that are publicly available and can be used by EPA and others.

Task 4 - Collection of Impact Data

Task 4 will begin near the completion of Task 3 after release data have been collected (i.e. Task 3 does not need to be completed before work on Task 4 can begin). The contractor shall collect impact data, not available in TRACI, that are needed to conduct the life cycle impact assessment phase of the LCA. Adhering to the QAPP for the task order, data shall be drawn from secondary data sources in the public domain to describe the fate, transport, and toxicity of chemicals and compounds found in alternate materials in computer monitor casings identified in the LCI as releases, or potential releases, to the environment (including potential exposure by humans). These data include impact factors toxicity data, mass transport coefficients, partitioning coefficients, and solubility (i.e., fate and transport) data.

Task 5 - Submission of LCI Data and Impact Data

The contractor shall submit Excel spreadsheets of the LCI data (collected in Task 3), as well as EcoSPOLD-compliant XML file for the processes following the template for LCI Unit Process Documentation (the template is attached in pdf format; the Word version will provided by the EPA) and the protocol established in the EPA's Standard Operating Procedure (SOP) for Life Cycle Assessment Projects Involving Data Collection. The Contractor shall submit the completed information in draft no later than 120 days after award of the contract. EPA will review the drafts and provide comments to the Contractor for preparation of final products.

The Contractor shall submit the results of Task 4 (impact data) in brief report (no more than 10 pages in Word format) outlining the key data points requested above, and highlighting data gaps that may affect the interpretation of the comparison based on the results of the LCAs, along with a list of key references and data sources, indicating data that are publicly available and can be used by EPA and others. The Contractor shall submit the completed information in draft no later than 120 days after award of the contract. EPA will review the drafts and provide comments to the Contractor for preparation of final products.

Task 6 - Market Analysis of Current and Future Plastics Recycling Infrastructure

Using readily available, publicly accessible data, the Contractor shall develop a market analysis of the current capacity for recycling plastics from electronics. To the extent possible, this analysis should include:

- Current volumes of end-of-life plastics generated by electronics recyclers that could be recycled into resin for new electronics. This will require an analysis of the flows of materials into and out of the current recycling infrastructure, by material type (e.g., how much plastic, metals, glass, other materials are currently being recycled, and how they are currently being used or disposed of). Much of the current plastic is being burned for energy recovery as part of the metal smelting process used to extract valuable metals from waste electronics.
- Number of companies, or facilities globally that are capable of recycling plastics from used electronics into plastics for new electronics, and the volumes these companies or facilities can process;
- Trends in the commodity values of waste plastics from electronics;
- Estimates of the required facilities, infrastructure, and/or investment needed to increase the supply of recycled content plastics by 5% 10% and 25% from current levels.

The results of the research should be a short report (about 10 pages) outlining the key data points requested above, and highlighting future scenarios for the market for recycled plastics.

Schedule:	Time to Completion
Task 1 QAPP	
Submission of Draft QAPP	20 days after award
Submission of Final QAPP	2 weeks from submission of EPA comments to Contractor
Task 2 Preparation of Background Material	
Draft Report	30 days after award
Final report	2 weeks from submission of EPA comments to Contractor
Task 3 Collecting Inventory Data	60 days after QAPP approval
Task 4 Collecting Impact Data	30 days after Task 3 completion
Task 5 Submission of LCI Data and Impact Data	
Draft LCI Data and Documentation	120 days after award
Final LCI Data and Documentation	2 weeks from submission of EPA comments to Contractor
Draft Impact Data and Report	120 days after award
Final Impact Data and Report	2 weeks from submission of EPA comments to Contractor
Task 6 Market Analysis	
Report Outline	Within 10 days of task start
Draft Report	120 days after award
Final Report	2 weeks from submission of EPA comments to Contractor

Work Task Management:

The Contractor shall initiate weekly communication (telephone conversation or electronic correspondence) with EPA to discuss progress on the data collection efforts, quality assurance procedures, and report preparation, throughout the effort. While a majority of the correspondence can be conducted through e-mail, the Contractor shall communicate verbally (teleconferences) no less than once a month.

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References

Boyd, Sarah B (2011) Bio-Based versus Conventional Plastics for electronics Housings: LCA Literature Review, The Sustainability Consortium White Paper #101, February 2011.

International Standards Organization (2006) *Environmental Management – Life Cycle Assessment – Principles and Framework, ISO 14040*.

International Standards Organization (2006) *Environmental Management - Life Cycle Assessment - Requirements and Guidelines, ISO 14044*. Brussels.

US Environmental Protection Agency (2006) *Life Cycle Assessment: Principles and Practice*, EPA/600/R-06/060.

US Environmental Protection Agency (2008) *Electronics Waste Management in the United States*. EPA/530/R-08/009.

US Environmental Protection Agency (2011) *Electronics Waste Management in the United States through 2009.* EPA/530/R-11/002.

Wang, H, Chang R, Sheng K, Adl M, and Qian X, (2008) Impact Response of Bamboo-Plastic Composites with the Properties of Bamboo and Polyvinylchloride (PVC). Zhejiang University, Hangzhou, P. R. China. http://dx.doi.org/10.1016/S1672-6529(08)60068-2.



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Process Name:	<enter -="" 50="" character="" limit="" name="" process=""></enter>						
Reference Flow:	<enter and="" flow="" name="" reference="" units,="" value,=""></enter>						
Brief Description:							
Section I: Meta Data							
Region:	US	State: <name></name>					
Year Best Represented:	уууу	County: <county></county>					
Category:	<category></category>	Geographic comment:					
Subcategory:	<subcategory></subcategory>	<no comments.=""></no>					
Process Scope:	<select from="" list=""></select>						
Allocation Applied:	<select from="" list=""></select>	Latitude: 					
Completeness:	<select from="" list=""></select>	Longitude: <longitude></longitude>					
Relevant Input Flows In	cluded in Data Set:						
Elementary inputs:	☐ Minerals ☐ Energy	☐ Water ☐ Other					
Technosphere inputs:	☐ Materials ☐ Energy	Transportation					
	Services Other						
Relevant Output Flows I	Included in Data Set:						
Releases to Air:	Greenhouse Gases	Criteria Air Pollutants Other					
Releases to Water:	☐ Inorganic Emissions	Organic Emissions Other					
Water Usage:	☐ Water Input	Water Returned to Environment					
Releases to Soil:	☐ Inorganic Releases	Organic Releases Other					
Adjustable Process Parameters:							
First parameter name	First	parameter description					
Second parameter nam							
Page 1 of 5							



Life Cycle Inventory Unit Process Documentation

Tracked Input Flows:

First input flow name [category name] Input flow description
Second input flow name [category name] Input flow description

. .

Tracked Output Flows:

Reference flow name [category name] Output flow description

Other co-product flow name if applicable Output flow description

[category name]

... ...

Section II: Process Description

Associated Documentation

Add text.

Goal and Scope

Add text.

Boundary and Description

Add text.

Life Cycle Inve	ntory Data - Proc	ess Documentation File
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Figure 1: Unit Process Scope and Boundary

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Table 1: Properties for <Process name>

Data Description	Value	Unit	Source

Table 2: Unit Process Input and Output Flows

1				
Flow Name÷	Value	Units (Per Reference Flow)		
Inputs				
Outputs				

^{*} Bold face clarifies that the value shown does not include upstream environmental flows. See also the documentation for embedded unit processes, as shown below.

References

Add text.

Section III: Document Control Information

Date Created: July 19, 2011

Point of Contact: Your name and email address here. List other co-authors here as

well.

Revision History:

Add text, for example: Original/no revisions

Reference information:

<Last name, First name, etc.> (2011). Life Cycle Inventory Unit Process Documentation:

<Process Name>. U.S. Environmental Protection Agency, National Risk Management Research

Laboratory. Version: <insert version, e.g. 0.1>, Last updated: <insert date>

Section IV: Disclaimer

Neither the U.S. Environmental Protection Agency nor any person acting on behalf of this organization:

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